

Design studies for a European Gamma-ray Observatory

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Carmen Baixeras^b, Denis Bastieri^h, Wlodek Bednarek^e, Ciro Bigongiari^h, Adrian Biland^p, Oscar Blanch^a, Rudolf K. Bock^g, Thomas Bretz^m, Ashot Chilingarianⁿ, José Antonio Coarasa^g, Sebastian Commichau^p, Luis José Contreras^f, Juan Cortina^a, Francesco Dazzi^h, Alessandro De Angelis^o, Barbara De Lotto^o, Carles Domingo^b, Eva Domingo^a, Daniela Dorner^m, Daniel Ferenc^d, Enrique Fernández^a, Josep Flix^a, Victoria Fonseca^f, Lluís Font^b, Nicola Galante^k, Markus Gaug^a, Jürgen Gebauer^g, Riccardo Giannitrapani^o, Maria Giller^e, Florian Goebel^g, Thomas Hengstebeck^j, Piotr Jacon^e, Okkie C. de Jagerⁱ, Oleg Kalekin^c, Daniel Kranich^d, Elina Lindfors^l, Francesco Longo^o, Marcos López^f, Javier López^a, Eckart Lorenz^g, Fabrizio Lucarelli^f, Karl Mannheim^m, Mosè Mariotti^h, Manel Martínez^a, Keiichi Mase^g, Martin Merck^m, Mario Meucci^k, Razmick Mirzoyan^g, Abelardo Moralejo^h, Emma Oña-Wilhelmi^f, Raul Orduña^b, David Paneque^g, Riccardo Paoletti^k, Mikko Pasanen^l, Donatella Pascoli^h, Felicitas Pauss^p, Nikolaj Pavel^j, Raffaello Pegna^k, Luigi Peruzzo^h, Alessio Piccioli^k, Massimo Pin^o, Raquel de los Reyes^f, Arnau Robert^b, Antonio Saggion^h, Alejandro Sánchez^b, Paolo Sartori^h, Villi Scalzotto^h, Aimo Sillanpää^l, Dorota Sobczynska^e, Antonio Stamerra^k, Leo Takalo^l, Masahiro Teshima^g, Nadia Tonello^g, Andreu Torres^b, Nicola Turini^k, Gert Viertel^p, Vincenzo Vitale^g, Serguei Volkov^j, Robert Wagner^g, Tadeusz Wibig^e, Wolfgang Wittek^g

- (a) Institut de Física d'Altes Energies, Barcelona
- (b) Universitat Autònoma de Barcelona
- (c) Crimean Astrophysical Observatory
- (d) University of California, Davis
- (e) Division of Experimental Physics, University of Lodz
- (f) Universidad Complutense, Madrid
- (g) Max-Planck-Institut für Physik, München
- (h) Dipartimento di Fisica, Università di Padova
- (i) Space Research Unit, Potchefstroom University
- (j) Fachbereich Physik, Universität-GH Siegen
- (k) Dipartimento di Fisica, Università di Siena
- (l) Tuorla Observatory, Pikkio
- (o) Dipartimento di Fisica, Università di Udine
- (m) Universität Würzburg
- (n) Yerevan Physics Institute, Cosmic Ray Division, Yerevan
- (p) Institute for Particle Physics, ETH Zürich

Abstract

In this note we discuss preliminary studies concerning a large-diameter gamma-ray telescope, to be part of an array of telescopes installed at the existing observation site on the Canary island of La Palma. One of the telescopes in the array will be MAGIC, presently the largest existing gamma ray telescope with the lowest energy threshold world wide. A second telescope of the same class is under construction. Eventually, we will want to install one or more devices giving access to even lower gamma-ray energy; they will be larger than MAGIC by roughly a linear factor two, and are code-named ECO-1000 (for a mirror surface of 1000 m²).

A lower energy threshold is the key to new understanding in the gamma-ray domain observable by ground-based Cherenkov telescopes. It will allow to cover wavelengths in overlap with foreseen (and past) satellite experiments. We discuss below the substantial physics potential made available by a lower energy threshold. We also show how larger telescopes and higher light collection efficiency can lower the observable energy threshold, substantiated by extensive simulations. The simulations also confirm that multiple telescopes, of the MAGIC or the larger class, can achieve higher sensitivity.

We discuss the technologies needed to reach the physical low-energy limit. They exist at the component level, but have to be field-tested; we propose to implement and integrate the most critical components in a MAGIC-class telescope, such that the eventual extrapolation to a larger device becomes a fully predictable step. If financing can be found, such tests can be completed on a timescale such that a proposal for the first true low-threshold (≤ 8 GeV) telescope can be made in 2007, and its construction completed in 2009/2010. Together, the future telescopes will constitute a European Cherenkov Observatory (ECO) with unprecedented attraction for the worldwide research community, a step we deem natural after having successfully installed MAGIC in 2003.

1 Executive Summary

We discuss a feasibility study concerning several critical prototype elements for a large telescope. We think of a telescope with a useful mirror surface of about 1000 m², called ECO-1000, which is characterized, compared to the existing MAGIC telescope, by

- improved and wavelength-extended sensitivity of photomultipliers
- fourfold mirror surface achieved with new technologies
- permanently active mirror focusing under computer control
- support structure of low weight, allowing accelerated telescope movement
- economic high-performance readout electronics, including signal processing

In more detail, we plan detailed studies and prototyping work in several areas:

- Light collection: large-surface photomultiplier tubes with high quantum efficiency and wavelength acceptance extending into the UV; dielectric foils for optimal light collection (Winston cones); new production methods for hexagonal mirror elements with an individual surface in excess of one square meter; mirror surfaces with the highest possible reflectivity; automated and robust methods for focusing the mirror elements

- Telescope structure: new materials for building a light-weight support structure; accelerated telescope drive motors; simulation of structure deformation, wind resistance and possible oscillations; wind protection of structure (e.g. a low-resistance cover and/or light-weight clam shell mirror-only dome, similar to that of the Liverpool 2m telescope on La Palma); anchoring of the azimuth rail with minimal deformation.
- Site related studies: geological and meteorological suitability of possible sites near MAGIC; estimation of additional needs for infrastructure like electrical power, roads, control room surface, lightning protection; environmental impact.
- Dissemination and data access studies: we believe that a multi-telescope observatory must provide access to the data to a community much wider than the collaboration that builds the detectors. At a time when it becomes obvious that much progress is to be made by multi-wavelength observations, this seems an obvious necessity. We want to adapt our operation structure and format, access and dissemination of our data to a broad international scientific community.
- Electronics and data acquisition: more economical and less power-hungry multi-channel readout with sub-nanosecond time resolution and full preservation of digital signal properties, with real-time analysis in programmable processing units; adaptation of the data interface to modern computer communication (e.g. Gigabit Ethernet or firewire): this is an area of extraordinarily rapid evolution and potential cost cutting;
- Physics: modeling of different physics processes; precise estimation of achievable energy and angular resolution, and their impact on the various physics goals; performance comparison of an ECO-1000 telescope with foreseen satellite experiments.

Many of these studies are guided by our experience in building and commissioning MAGIC. Not all of them are technologically challenging as to require more than the developments we will carry out in the framework of building a copy of MAGIC, itself already containing multiple innovations.

The experience of developing MAGIC and bringing into operation this telescope, which has the presently lowest energy threshold of all gamma ray telescopes, will be invaluable for the next steps. The European La Palma site is already home for MAGIC, and has been so, in the past, for several gamma ray and air shower experiments. The site is also being used by multiple first-rate optical telescopes. The location has clear advantages over many other sites, including those proposed at high altitude. With MAGIC and the proposed telescopes, La Palma will become an observatory for gamma rays, unequalled in the Northern Hemisphere. We are convinced that the development of ECO will make major contributions in resolving present questions in fundamental physics and cosmology.

We explicitly want to express our openness to a close scientific collaboration with other experiments (HESS, Veritas, Cangaroo), following a development line close to that of MAGIC, with a view of installing optimal gamma ray observation possibilities in the Northern and Southern Hemisphere. We would expect the eventual instruments to run in close collaboration.

The total cost of the studies should be of the order of 5 MEuro, the timescale expected is not more than 3 years. A detailed proposal for a large-size device (ECO-1000) will be completed toward the end of this period, viz. in 2007 or 2008, and construction can start shortly afterwards, for a possible completion in 2009/2010. The cost of ECO-1000 is estimated today at 15-20 MEuro.

2 Introduction

MAGIC was designed back in 1998 with the very clear goal to lower the energy threshold at which gamma rays can be observed [1]. As the first MAGIC telescope has started operation and is now, in early 2004, on the way to reach its design performance, it is likely that, beyond the physics that has been predicted, unexpected avenues will open. Many unanswered physics questions loom in the low energy range, and we are confident that several of them will already be answered by MAGIC. The instruments of ECO, in particular the eventual larger telescope(s), will subsequently be able to extend the energy limit to even lower values, close to the lowest energies accessible to the Cherenkov technique, and to fully explore this range of wavelengths.

The energy threshold is primarily a question of two components: photon detection efficiency and mirror surface. Fast electronics resulting in signal integration over a short time is also an important handle to suppress background, and contributes to observing showers at lower energies. A natural evolution of the MAGIC principles, therefore, will be to take advantage of technological progress in light detection and the building of large structures, viz. the construction of a larger and more performant telescope. The mirror surface must be pushed to the technical limit without taking undue risks. To be constructed with a large mirror surface, maintaining a fast slewing possibility, the telescope structure must be made light-weight and easy to assemble. For high sensitivity, photodetectors must be brought to the highest possible quantum efficiency, and the light collection along the optical path must be optimal.

These are goals that have already guided the construction of MAGIC. The addition to MAGIC of further telescopes, on the Roque de los Muchachos site (La Palma), constitutes the initial step in building up a gamma ray observatory, the European Cherenkov Observatory or ECO. The experience gained during the construction of MAGIC, and progress in industrially available components and production methods do allow an improvement program, for a future second telescope of the MAGIC type. A so far rather unchanged copy of MAGIC is already under way.

With some additional support, this telescope can incorporate key innovations in technology, viz. the latest commercially available photodetectors, a new light-weight structure supporting highly reflective aspherical mirrors, and much improved mirror control that does not interfere with observations. Prototypes developed in that framework, and an accompanying feasibility and design study will pave the way for a substantial future leap in telescope size, i.e. towards ECO-1000.

First results from the MAGIC observatory are being obtained now (early 2004), and will likely turn out to be the start of a bonanza of sources understood or discovered, beyond the ones which we are guided to by the EGRET (in the future: GLAST) catalogues. Many sources will require detailed study, for which small-angle telescopes like MAGIC or ECO-1000 are ideally suited.

This report is structured as follows: The physics arguments are presented in the next section 3. Sections 4 and 5 discuss the characteristics of the gamma signal and the

expected sources of backgrounds, and the conceptual choices for a low-energy telescope, based on simulations of gamma ray induced showers and background. We concentrate on a comparison between the present MAGIC and both a MAGIC with a high-QE camera and an ECO-1000 telescope, also with a high-QE camera. In section 6, we discuss specific problems associated with opening the low energy sector. We then follow, in section 7, with a discussion of the practical implementation, viz. a crude work plan.

3 The Physics

We discuss in this section the potential in both astrophysics and fundamental physics by observing gamma rays in the energy range from 5 GeV up, thus accessing a range not observed with sufficient sensitivity by satellite experiments, and creating an overlap with these devices. In short, we try to answer the question *why go for a low energy threshold?*

The case for low threshold concerns a whole plethora of subjects, among them

- Supernova remnants and plerions: observations at low energy will help in discriminating between the various acceleration mechanisms assumed to be at the origin of VHE gammas.
- Pulsars: The known pulsars have cutoff energies of their pulsed emission in the few-GeV range, hence their detection will become possible by lowering the IACT threshold.
- Unidentified EGRET sources: an enormously rich field of activity for detailed studies, possible with modest observation times on nearly half of the observable EGRET sources.
- Fazio-Stecker relation: observation at lower threshold implies access to larger redshifts, and multiple AGNs up to redshifts 2 will help in determining the FSR (gamma ray horizon) determined by the infrared background light, resulting in better understanding of the cosmological evolution of galaxy formation, and the role of dust-obscured galaxies.
- Quantum gravity: the search for effects using time delays as a function of energy, in a large number of sources, will improve with lowering the threshold, due to an increased number of potential time-variable gamma ray sources, and the larger distances to them.
- Dark matter: the allowed space for the many theoretical models of dark matter may well be restricted by a systematic search for neutralino annihilations. The recently discovered difficulty due to low flux in the expected sharp energy peak from neutrino annihilations, can only be overcome by lowering the threshold to identify the continuum signature.
- Nearby galaxies: their expected steep energy spectrum makes observations at low energy a particularly good argument, as they allow enough flux to be detected in the gamma ray domain.

The details concerning physics becoming possible with a low energy threshold gamma telescope are given in the following paragraphs. In all cases, the argument can be made that approaching the physical limit of detectability for gammas (~ 2 -3 GeV) will give access to information presently not available from any instrument, and will in many cases allow to discriminate between competing theoretical models. We are confident that these arguments will be borne out, at least in part, already by the results from MAGIC, which has started taking data in late 2003.

Fundamental Physics and Exotics

Fazio-Stecker relation

Gamma rays from distant sources interact in the intergalactic space with infrared photons, and are substantially attenuated. The flux reduction depends on the photon energy and on the distance (redshift) of the source; the Fazio-Stecker relation (FSR [18], or Gamma Ray Horizon) is commonly defined as that energy for each redshift for which the photon flux is reduced by a factor e .

The detection of sources beyond the FSR is extremely difficult, due to the strong flux suppression. This has been a strong argument for lowering the energy threshold for the present generation of instruments (MAGIC). If their performance is as predicted, sources up to redshifts $z \sim 2$ will become accessible, at least at small zenith angles. Observations at larger zenith angles and uncertainties in the models of the extragalactic background light (EBL) [30], seem to suggest that this goal can be reached only with difficulty. Lowering the threshold to few GeV will provide enough lever arm to measure with precision the exponential energy cutoff due to cosmological absorption, which reaches about 20-40 GeV. Also, measurements of cosmological parameters through a determination of the FSR [31] should become possible with a large sample of AGNs distributed over a range of redshifts up to $z \sim 4$.

Quantum Gravity

Astronomical objects have been proposed as good laboratories to study fundamental physics, not accessible by accelerator facilities on Earth because of the huge energies and masses necessary to show measurable effects. In particular, Gamma Astronomy and Imaging Air Cherenkov Telescopes (IACTs) have been proposed to observe possible effects due to a quantum formulation of gravity [32].

Formulations of Quantum Gravity contain naturally quantum fluctuations of the gravitational vacuum, and lead to an energy-dependent velocity for electromagnetic waves. In other words, gammas of different energy produced simultaneously in an extragalactic object, arrive on Earth at different times due to their propagation through the gravitational vacuum. This Quantum Gravity time delay allows to measure Quantum Gravity effects. The speed dispersion relation might be quite different for each Quantum Gravity formulation. The differences are small in all possible models, and can be studied from a phenomenological point of view only. Typically,

$$\Delta t = \eta(E/E_{QG})^\alpha$$

where E_{QG} is an effective energy scale of Quantum Gravity (i.e. must be close to the Planck mass), α is the first non-zero leading order, and η is proportional to the gamma path from the source to the observer, to a good approximation the distance to the source.

The equation above predicts the largest time delays for the most energetic gammas. A low energy threshold will thus not help directly in this measurement, but will have

indirect effects. An energy threshold at zenith of few GeV will allow to have energy thresholds of tens of GeV at medium-to-large zenith angles, leading to effective areas larger by an order of magnitude, and hence will collect 10 times more gammas than the present IACTs in the same energy range. One of the major problems in the measurement of time delay, viz. the lack of gammas at medium-to-large energies, can thus be overcome. Also, any time delay effect must be studied over a wide range of redshifts, in order to disentangle any Quantum Gravity effect from source-dependent time delay emission effects. For this reason, a large number of sources at different redshifts must be detected and measured with some precision. A low-energy threshold detector as ECO-1000 will be an ideal instrument for such studies.

Dark Matter Search

Cosmology provides strong arguments, in explaining the observed Universe Structure, that some 25% of the energy in the Universe is in the form of Dark Matter, most of it "cold" and much of it as non-barionic relic "Weakly Interacting Massive Particles" (WIMPs). WIMPs should constitute a clumpy halo around galaxies, and concentrate around the galaxy center and in dwarf spheroidal satellites (dSph), identifiable by having a large mass-to-light ratio [33].

The Standard Model of Particle Physics has no candidate for WIMPs, and the nature of Dark Matter can only be explained by going beyond [34]. Supersymmetric Theories are among the most popular extensions to the Standard Model. They assume a symmetry between the fermionic and bosonic degrees of freedom, providing a Grand Unified framework for the fundamental coupling constants in agreement with the high precision collider measurements, and giving an elegant solution to some fundamental theoretical loopholes of the Standard Model. Supersymmetry (SUSY) also provides a quite natural candidate for the WIMP, the Neutralino. SUSY particles, if they exist, shall be detected at the Large Hadron Collider (LHC). The Neutralinos could be the Lightest Supersymmetric Particles (LSP) and, if R-parity (a quantum number associated to the new SUSY particles) is conserved, should, therefore, be stable. They are weakly interacting since they are a mixed state of the SUSY spin partners of the neutral electroweak gauge bosons (Gauginos) and the two neutral Higgs bosons which are mandatory in SUSY theories (Higgsinos).

Relic Neutralinos may, in principle, be detected directly through their elastic scattering while they impinge on instruments on Earth. In addition they might be indirectly detected by their annihilation through different channels, producing finally high energy gammas and neutrinos [35]. Several annihilation channels lead to the production of high energy gamma rays in the range of present and future Cherenkov telescopes; of these, $\chi\chi \rightarrow \gamma\gamma$ and $\chi\chi \rightarrow Z\gamma$ would provide ideal observational results (monochromatic annihilation lines), but are strongly suppressed. Instead, the most probable reaction is $\chi\chi \rightarrow jets \rightarrow n\gamma$, which could be observed as an energy distribution in γ s different from the power laws characteristic for the cosmic acceleration mechanisms.

Supersymmetric Theories have multiple free parameters, but the requirement that they provide Grand Unification and a satisfactory answer to the theoretical clues of the Standard Model, together with the constraints from the non-observation of their effects up to now, restricts their parameter space. A set of parameter space benchmark points (A-M) incorporating all these constraints have been suggested by the SUSY-search community, and provide a clear framework to make predictions for future SUSY hunting at accelerators and in other detectors [36].

Figure 1 shows flux predictions for these benchmark points, as a function of the photon energy threshold for gamma rays produced by relic Neutralino annihilations

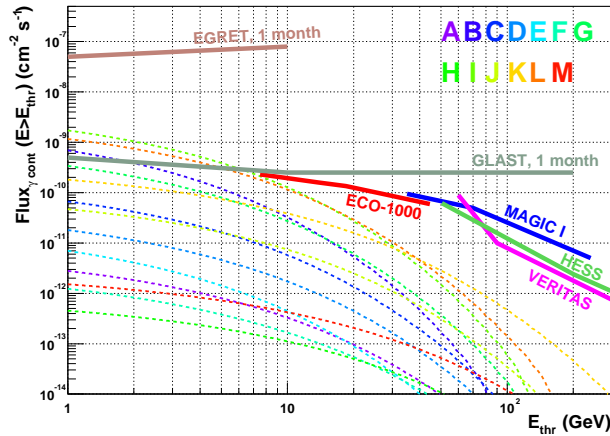


Figure 1: *Integrated gamma flux as function of photon energy threshold, for gammas produced by relic annihilations in the galactic center, assuming a moderate halo parameter of $J=500$. A to M are the Post-LEP SUSY benchmark points, extracted from [37]. The point source flux sensitivities for several gamma ray detectors are also shown.*

in the galactic center [37]. A moderate halo density profile $J=500$ has been assumed; for particularly cuspy halo models, such as those in [38], the model fluxes are higher by two orders of magnitude, leading to detectable signals in GLAST and MAGIC. There is no clear feature in the spectrum, the only way of discriminating against the astrophysical background is to study the energy spectrum within at least one decade in energy. For that, a Cherenkov telescope such as ECO-1000 with low threshold and high flux sensitivity is mandatory. The fact that the galactic center is at large zenith angle for Northern Observatories, argues again for a low energy threshold in the search for Neutralino annihilations at the galactic center.

Gamma Ray Bursts

Nearly 3000 Gamma Ray Bursts (GRBs) have been observed by BATSE, but the phenomena causing them are still a mystery. Even the successful simultaneous observation of some GRBs at different wavelengths has not helped to find a favorite among the numerous existing theoretical models. The GCN (GRB Coordinates Network) is an attempt to encourage multiwavelength observations, by distributing information coming mainly from satellites, in real time. We know at least that there exists an *afterglow*, which follows immediately the burst itself, normally lasting longer for observations at lower energy. GRBs last between a few seconds and minutes, the X-ray emission typically runs on a scale of days, and the optical one even on a scale of weeks.

Some BATSE observations (less than a percent) were complemented by EGRET, at ~ 1 GeV of energy; however, both the field of view (FOV) and the sensitivity of EGRET did set severe limits. Encouraging is the fact that two of the EGRET-detected GRBs (GRB930131 and GRB940217) lasted longer inside the EGRET energy window than the observation in BATSE, so that an afterglow at higher energies can not be excluded, for some GRBs¹.

¹The existence of exceptionally long GRBs, where the gamma ray emission lasts clearly longer than the one in the hard X-ray range, is particularly challenging for theoretical models, that have to deal with a continuous acceleration process at a substantially higher energy than that of the prompt emission

ECO-1000 will be in a better position than EGRET: the limited FOV can be compensated by the fast repositioning system, and the sensitivity is greatly increased by the calorimetric observation of gamma rays typical of Cherenkov instruments.

Astrophysics

Supernova Remnants

Shell-type supernova remnants originating in core-collapse supernovae, have long been suggested to be the sites for cosmic ray acceleration below 100 TeV, mainly on the basis of general energetics arguments [40]. We know from their synchrotron, radio and X-ray emission that electrons are accelerated to TeV energies.

However, there is no direct evidence for proton acceleration. A possible signature of proton acceleration would be the spectrum of π^0 decay from collisions of cosmic ray protons and nearby matter like high density molecular clouds [41]. A number of shells have been observed by EGRET at 0.1-10 GeV energies [42], [43], and by IACTs at TeV energies [44], [45], [46]; nevertheless, the origin of this radiation remains uncertain, due to the contamination of γ -rays produced by leptonic processes (Bremsstrahlung or Inverse-Compton).

A low energy threshold Cherenkov telescope will be instrumental in disentangling both emissions, either through the different spectral shape or through resolving γ -ray features that coincide with high density matter regions. A low threshold and increased sensitivity will allow spectral studies in the >10 GeV range, where the different mechanisms are expected to show different spectral shapes [48]; it also may allow to pin down the exact positions of possible spectral cutoffs. Increased photon statistics at energies around 1 GeV may allow to reject pulsars. An angular resolution close to 0.1° at energies below 10 GeV may allow to discriminate regions of enhanced matter density in direct interaction with the SNR shock, point source emission from pulsars, extended emission coincident with plerions, or regions of low density where the emission is most probably due to leptonic processes.

Plerions

Plerions or Pulsar-Wind Nebulae are SNRs in which a pulsar wind injects energy into its surroundings. A bubble is inflated out to a radius where it is confined by the expanding shell, as already suggested by [49] for the Crab Nebula. Particle acceleration is expected in the wind termination shock.

Figure 2 shows the Crab plerion spectrum measured by EGRET at energies up to 10 GeV, and by Whipple and CANGAROO at TeV energies, along with the predicted spectra for different models [50], [51], [52]. The VHE emission is probably due to Inverse-Compton of $\Gamma > 10^8$ electrons. The observed synchrotron X-ray emission confirms the existence of these extremely high energy electrons, while the dynamics of the particle flow only yield $\Gamma \sim 10^6$ for the postshock region.

A precise measurement of the spectrum in the 1-100 GeV energy range is crucial to constrain the model parameters and to ascertain if another source of photons is necessary, possibly Bremsstrahlung from dense regions of gas.

Pulsars

The observation of gamma ray pulsars in the GeV domain is of special interest: in this range, the EGRET pulsar spectra have a cut-off, and observing the differential spectrum of a gamma ray pulsar will discriminate between the polar cap and outer gap models for emission. The two models predict different cut-off energies, below 50 GeV for the polar cap, up to 100 GeV for the outer gap model [53], [54].

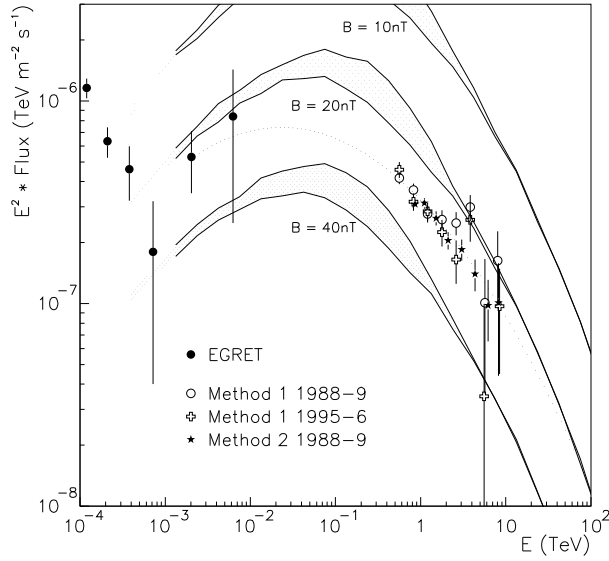


Figure 2: *Predicted IC spectrum according to the references in the text, compared to the EGRET, Whipple (method 1 and 2) and CANGAROO observed spectra*

GLAST will extend the exploration of the gamma ray sky up to 300 GeV, and will have, at GeV energies, a sensitivity many times higher than EGRET, but its limited detection area will restrict its capability in the high-energy range. MAGIC will observe pulsed emissions in the non-imaging mode, and not far from its energy threshold. The expertise and know-how of MAGIC will be a key factor for exploring ECO-1000 with its absolute energy limit of 2 to 3 GeV, close to the threshold energy for secondary electrons to radiate Cherenkov light in the upper atmosphere. In ECO-1000, pulsars can be measured in both imaging and non-imaging mode. The first estimations of observation times and our calculation of collection areas show how much ECO-1000 can be superior to MAGIC:

Object (pulsar)	$K \times 10^8$ $cm^{-2}s^{-1}GeV^{-1}$	Γ	$T_{ECO-1000}$ [minutes]	T_{MAGIC} [hours]
Crab	24	2.08	9	1.2
Geminga	73	1.42	26	24.7
PSR B1951+32	3.8	1.74	44	3.2
PSR J0218+4232	1.9	2.01	1860	39.5
PSR J1837-0606	5.5	1.82	90	17.1
PSR J1856+0113	7.4	1.93	84	17
PSR J2021+3651	11.5	1.86	25	49
PSR J2229+611	4.8	2.24	852	200

In this table, we estimate the observation times to achieve a 5σ significance. K is the monochromatic flux at 1 GeV, and Γ is the spectral index of the source. The improvement in detection time is substantial (collection areas for MAGIC and ECO-1000 are shown in figure 15).

Active Galactic Nuclei

Galaxy formation and evolution in the early universe is one of the main open questions of extragalactic astronomy. The conventional understanding is based on a co-evolution of galaxies and super-massive black holes, which power the AGN phe-

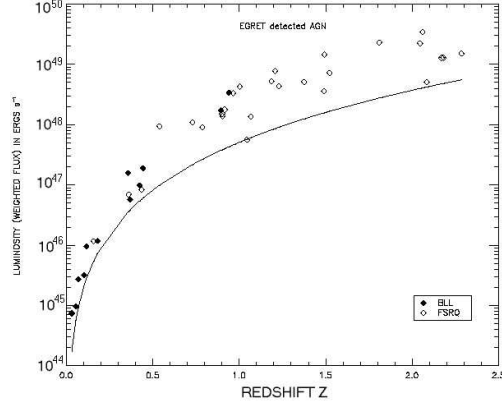


Figure 3: *AGN luminosity at different redshifts, as measured by EGRET*

nomenon. Recent observations, however, seem to challenge this understanding, by showing early star and galaxy formation, compared to a later evolution of AGNs.

Gamma ray observations of AGNs at all redshift will help in understanding the evolution of AGNs and their central engines, super-massive black holes. The high-energy gamma radiation emitted at close distances from the black hole is also a fundamental ingredient for multi-wavelength studies. The low threshold of ECO-1000 will enable us to study the gamma ray emission of a large population of AGNs, up to redshifts above $z = 2$, as the lower-energy gammas can reach us largely unabsorbed by the meta-galactic radiation field.

Microquasars and X-ray Binaries

X-ray binaries provide a nearly ideal laboratory to study nearby objects of strong gravity, presumably black holes of a few solar masses, remaining from the core-collapse of short-lived massive stars through their high-energy emission. The sources are natural candidates for gamma rays up to at least GeV energies. The magnetic field frozen into the ionized, differentially rotating accretion disk around the black hole in a binary system, can twist and reconnect to release the energy stored in the magnetic field into the kinetic energy of coronal particles. Short-lived, large-scale electric fields can accelerate charged particles up to high energies, scaling from numerical simulations of magnetic reconnection in the solar magnetosphere, the Earth's bow shock, and the geomagnetic tail [55]. Jets forming in radio-emitting X-ray binaries and the gamma ray emission observed with EGRET up to 10 GeV are indicative of particle acceleration processes occurring at shocks in these super-Alfvénic flows.

Among the X-ray binaries, microquasars form a particularly interesting subclass, exhibiting relativistic jets as inferred from superluminal motion of radio knots. Non-thermal radio-to-X-ray emission extends through the inverse-Compton process into the GeV-TeV domain and should be observable [56]. In particular, microblazars (microquasars with their jet axes aligned roughly to the line of sight of the observer) promise to be an interesting target, for studies of short-term variability. Microblazars might even be observable from nearby galaxies due to their Doppler-boosted flux.

One important question concerns the fraction of cosmic rays accelerated in blazars, taking into account the beamed-away fraction of the sources. If microquasars can be established as powerful sources of gamma rays in the >10 GeV range, a new paradigm for cosmic ray acceleration in explosive sources such as Supernovae (and their remnants) and Gamma Ray Bursts might emerge, in which quasi-steady sources such as Radio

Galaxies, BL LACs, and Microquasars are responsible for most of the cosmic rays [57].

Diffuse Photon Background

The diffuse photon background may be classified according to its origin : The Extragalactic Background Radiation (EBR) and the Diffuse Galactic Emission (DGE). EBR is essentially isotropic, and is well established up to energies of ~ 50 GeV [58]. In the energy range from 30 GeV to 100 TeV, a large part of the EBR may be due to the direct emission from Active Galactic Nuclei (AGN), which have not yet been resolved [59, 60]. Direct measurements of the DGE exist up to energies of ~ 70 GeV [61]. The data are explained by the interaction of cosmic-ray electrons and hadrons with the interstellar radiation fields and with the interstellar matter [62, 63]. The production mechanisms are synchrotron radiation of electrons, high-energy electron bremsstrahlung, inverse Compton scattering with low-energy photons, and π^0 production by nucleon-nucleon interactions.

New measurements of the gamma radiation (either diffuse or from point-like or extended sources) in the 10 to 300 GeV energy region will help to better understand the different sources of the diffuse gamma ray background :

- By the detection or identification of new AGNs one will test the unresolved-blazar model for the origin of the apparent EBR. The basic assumption is an average linear relationship between gamma ray and radio fluxes. Such a relation is suggested if the same high-energy electrons are invoked as the source of both the radio and gamma ray emission [64].
- A deep observation of new blazars, with measurement of redshift, energy spectrum, and cutoff energy, will allow a more reliable determination of the collective luminosity of all gamma ray blazars. A good knowledge of this contribution is a precondition for future tests of the predictions of the cascading models for the EBR.
- The detection or identification of new SNRs and pulsars will allow better estimates of their contribution to the DGE.
- Measuring the absolute diffuse gamma ray flux (mainly DGE) as a function of energy, galactic latitude, and longitude, will yield new information about the origin and propagation of galactic cosmic rays, and about the spatial distribution of the interstellar matter, radiation and magnetic fields.

Unidentified EGRET Sources

The EGRET experiment (1991-2000) has given us the first detailed view of the entire high-energy gamma ray sky. Many of them, including blazars, have not been detected by IACTs. Of the 11 VHE gamma ray sources known today, 6 are Blazars and 5 SNRs/Plerions. About half of these have been observed by EGRET.

We can thus classify the VHE sources: (a) sources with a steep cut-off which are detected by EGRET, but become unobservable above a few 100 GeV, (b) flat spectrum sources like Mkn501, which only become observable at energies well above 100 MeV, and (c) intermediate cases like Mkn421 or the Crab Nebula. Most known sources must belong to type (a), given the way observation technology has developed.

The number of detectable sources decreases rapidly with rising energy threshold, even though the point source sensitivity already of present Cherenkov telescopes is many orders of magnitude better than that of EGRET. It seems that the universe

becomes abruptly much darker above a few 100 GeV. In other words, the cut-off of most high-energy source spectra seems to take place in the range 1 - 200 GeV. The first decade of energy in this range has been covered by EGRET and 57 sources have been detected [65]. The range from 10 to 200 GeV, however, has never been explored until today, and it is this “gap” that forms the major incentive behind more sensitive Cherenkov telescopes like ECO-1000.

We have estimated observation times (5σ) for the observable EGRET sources, and found that $\sim 40\%$ of them can be studied by ECO-1000 in very few hours or less. The accessible sources touch all fields of high-energy astrophysics, and their observation will much contribute to constraining existing models in the energy domain where cut-offs set in.

Galaxy Clusters

Galaxy clusters contain a hot, intracluster medium (ICM), which acts as a storage volume for cosmic rays escaping from galaxies in the cluster, and from active galactic nuclei [66]. The total energy and the spectrum of the stored relativistic particles is unknown, and gamma ray observations would provide important clues about their origin. It is important to distinguish this emission component from others, possibly related with the annihilation of supersymmetric dark matter particles. Due to the expected steepness of the cosmic ray spectrum in the ICM, it is important to achieve a low gamma ray threshold. Other suspected sources of relativistic particles are the supersonic motion of galaxies through the ICM and the accretion of material from metagalactic space onto the cluster which induce the formation of gigantic shock waves possibly accelerating particles up to the highest observed energies [67]. The observed nonthermal radio-to-UV emission in clusters ensures the production of gamma rays through the inverse-Compton scattering process. There is also a contribution of gamma rays due to a calorimetric effect based on the pair production process. The gamma rays from sources residing in the cluster and above threshold for pair production with microwave background photons convert into pairs, which subsequently scatter microwave background photons to higher energies shaping a gamma ray halo [68].

Starburst Galaxies

The Cherenkov telescope CANGAROO has recently reported the first detection of a normal spiral galaxy at TeV energies [69]. NGC 253 is a nearby (~ 2.5 Mpc) starburst galaxy, in which a high cosmic ray density and non-thermal emission are expected. The source is extended with a width of $0.3\text{-}0.6^\circ$ (corresponding to 13-26 kpc), and temporally steady over two years. It can be considered the first of a new class of extragalactic objects, clearly different from the other observed extragalactic TeV emitters (AGNs of the BL Lac class). The TeV γ -rays may come from hadronic or leptonic processes originating from the cosmic ray density in a starburst (assumed high). Figure 4 shows the multiwavelength spectrum of NGC 253 and estimates of the hadronic and IC emission produced by disk and halo electrons (from [70]).

Romero et al. [71] have advanced an alternative explanation based on hadronic processes in the core of the galaxy. They suggest that proton illumination of the inner winds of massive stars could produce TeV γ -rays without the unobserved MeV-GeV counterpart. The enhancement in cosmic ray density would be produced by collective effects of stellar winds and supernovae.

Precise spectral measurements by ECO-1000 in the range 1-100 GeV will allow to constrain the different models; the angular resolution around 0.1° will help to localize the source of emission at low energies. Nearby starburst galaxies are ideal targets for this kind of studies.

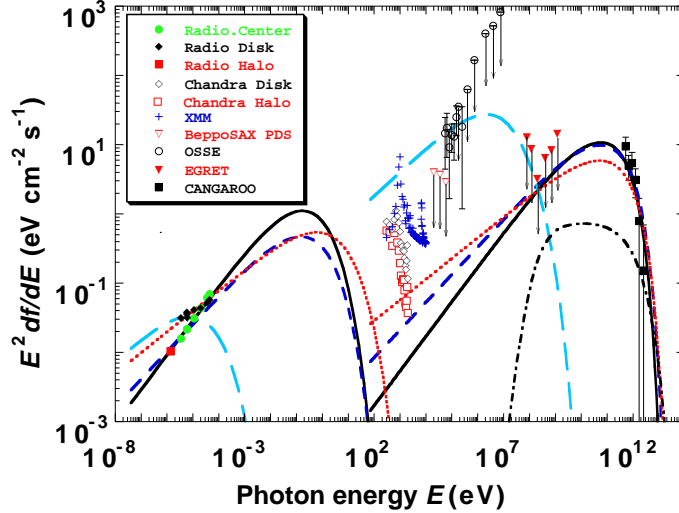


Figure 4: *Multiwavelength spectrum of the starburst NGC 253, along with a model of the electron IC emission in the halo (for two different electron spectra, solid black and dashed blue), in the disk (red), IC localized in the galactic center (dashed cyan), and π^0 decay*

Nearby Galaxies

Nearby galaxies such as M31, M82, Arp 220, and Cen A are representative of normal spiral galaxies, starburst and merger galaxies, and active galactic nuclei. Owing to their vicinity, the morphology of these galaxies and their multifrequency properties have been studied in great detail, but lack information in the 5 GeV-300 GeV region. In normal galaxies, star formation and hence the production of collapsing massive stars with associated gamma ray production in GRBs, supernovae and their remnants can be probed with a low-threshold IACT like ECO-1000 [69, 71]. The low threshold of 5 GeV is important to observe enough flux for their detection, since the spectrum of cosmic rays (and hence gamma rays) is expected to be very steep (-2.75 in our Galaxy).

The Galactic Center

The Galactic Center (GC) region, excepting the famous Sgr A*, contains many unusual objects which may be responsible for the high energy processes generating gamma rays. The GC is rich in massive stellar clusters with up to 100 OB stars [72], immersed in a dense gas within the volume of 300 pc and the mass of $2.7 \times 10^7 M_\odot$, young supernova remnants e.g. G0.570-0.018 or Sgr A East, and nonthermal radio arcs.

In fact, EGRET has detected a strong source in the direction of the GC, 3EG J1746-2852 [73], which has a broken power law spectrum extending up to at least 10 GeV, with the index 1.3 below the break at a few GeV. If in the GC, the gamma ray luminosity of this source is very large $\sim 2 \times 10^{37} \text{ erg s}^{-1}$, which is equivalent to ~ 10 Crab pulsars. Up to now, the GC has been observed at TeV energies only by the HEGRA Collaboration [74]. The upper limit has been put on 1/4 Crab (results from the CANGAROO-II Collaboration are expected at ICRC 2003). High energy gamma rays can be produced in the GC in the non-thermal radio filaments by high energy leptons which scatter background infrared photons from the nearby ionized clouds [75], or by hadrons colliding with dense matter. These high energy hadrons can be accelerated by the massive black hole, associated with the SGr A* [76], supernovae [77], or an energetic pulsar [78]. In order to shed new light on the high energy phenomena in the GC region, and constrain the models above, new observations with sensitivity down to

10 GeV are necessary.

ECO-1000 and GLAST

The successor of EGRET, the Gamma ray Large Area Space Telescope (GLAST) [2], is scheduled for launch in September 2006. The mission duration will be at least 5 years, more likely 10 years. GLAST will have an effective collection area just under 1 m² and will be able to detect gamma rays with good energy and direction resolution between 0.1 and 300 GeV. In the overlap region, from 5 to 300 GeV, GLAST and ECO-1000 will perfectly complement each other.

GLAST is a survey instrument. It has a very low background counting rate at energies above a few GeV, and it has a large field of view. Over its lifetime, GLAST is predicted to discover thousands of new sources. However, these detections will be severely photon-limited above a few GeV: From the Crab Nebula, which is a strong source, GLAST will detect ≈ 3500 photons above 1 GeV per year, 400 of these photons will be above 10 GeV, and only about 23 photons will be above 100 GeV [3]. For a source significantly weaker than the Crab Nebula it will not be possible to measure the spectrum above 10 GeV with an accuracy adequate for constraining source models, even though the source may be clearly detected. The low photon detection rates will also lead to a strong limitation for studies of short-term variability above a few GeV.

ECO-1000, on the other hand, will have a high background rate and relatively small field of view, but an effective collection area four to five orders of magnitude larger than that of GLAST. Hence, given the positions of sources discovered by GLAST, ECO-1000 can deliver spectra above 5 GeV which have higher accuracy and better time resolution for variability studies. In other words, GLAST will discover the sources and measure their spectra and variability from 0.1 - 5 GeV while ECO-1000 will complete the spectra and variability studies from 5 GeV to where the sources cut off. GLAST and ECO-1000 form an ideal pair of complementary instruments.

The large overlap region from 5 to 300 GeV will allow a good cross-calibration such that high-accuracy spectra can be constructed, spanning an energy range of more than three orders of magnitude from 0.1 GeV to 1000 GeV or wherever the sources cut off.

Multiwavelength Studies of Active Galactic Nuclei (AGNs)

The study of blazars - active galaxies radiating across the whole electromagnetic spectrum from radio to gamma/TeV rays - requires multifrequency, multiapproach studies. We should recall that a single observation in the 1990s had a large impact on the study of AGNs: the Compton Gamma Ray satellite Observatory (CGRO) found that a major fraction of energy is radiated in gamma rays. This allowed the conclusion that all electromagnetic frequencies from radio to gamma rays are very closely connected. Later, some blazars were found by ground-based IACTs to be extremely energetic even at TeV-energies. We can conclude that measurements at the wavelengths becoming available to us by decreasing the energy threshold, will contribute important knowledge to this sector.

While this general framework is known, the complicated correlations between various phenomena at different energies make it extremely difficult to study the details without access to simultaneous data across the entire electromagnetic range. Broadly speaking, the spectral energy distribution of all radio-loud AGNs consists of two maxima, one from radio to UV/X-rays, produced by synchrotron radiation, the other from X-rays to TeV caused by inverse Compton (IC) radiation. No details can be understood without studying the entire spectrum. It seems assured, then, that good observations in the energy range, which we try to open together with GLAST, viz. from 5 to 50 GeV,

will be a key contribution in understanding blazars.

A crucial question to study is the nature of the seed photons. The accretion disk of AGNs is the most obvious source of photons, mainly in the UV. These photons can also be reflected/reprocessed by the broad line region clouds, producing an intense optical photon field. Farther away, dust heated to 500-1000 K is a source of infrared photons. All these are called external Compton (EC) scenarios, since the seed photons come from outside the jet. The synchrotron photons in the jet can also scatter from the electrons which produced them, in which case we have a synchrotron self-Compton scenario (SSC). In the EC models, the high frequency emission must originate within a small fraction of a parsec from the AGN core, since the photon density drops rapidly with distance. As the synchrotron-emitting shocks typically reach their maximal development much further downstream, the gamma ray variations should precede the onset of the radio flare. Since the external photon field is independent of the electron density in the jet, the EC flux should change linearly with the synchrotron flux. In the SSC scenario the change should be quadratic, since the synchrotron photon density is also changing, not just the electron density. The SSC gamma rays can be emitted simultaneously with, or even after, the onset of the radio flare.

MAGIC (and future gamma-ray telescopes in La Palma) have straight access to synchronous dedicated optical observations, being associated with the KVA optical telescope, situated next to the MAGIC site on La Palma. This is the only Cherenkov Observatory with such a facility. Besides standard UBVRI-photometry, KVA will also be the only telescope in Europe with simultaneous polarimetric monitoring capability, a crucial asset in, e.g., separating thermal and non-thermal contributions to the total flux. The KVA telescope will soon be fully automatic.

Simultaneous observations in GeV/TeV and optical energies are extremely important when we expect to increase the number of detected sources dramatically as we reach lower energy threshold (thus avoiding the IR-background absorption), using MAGIC and, eventually, the ECO-1000 telescope. In TeV-blazars, the optical synchrotron flux (highly polarized) should be connected to the GeV/TeV fluxes. While contributions to the lower energy IC flux may come from a wide electron energy range, and from several processes, including thermal X-rays close to the accretion disk, only the very highest energy electrons can boost the seed photons to the extreme TeV energies. The TeV variations are, therefore, a very pure IC signal, and it should in principle be easy to identify the 'parent' synchrotron component on the basis of correlations and time lags. Observations of TeV flares have provided intriguing hints, but no definite answers due to insufficient simultaneous optical and GeV/TeV data. With joint observations of KVA and MAGIC/ECO-1000, the answers are within our reach.

4 Signal and Backgrounds in the few GeV Domain

The following paragraphs are the result of extensive simulations at low energies, up to 200 GeV, for gammas and electrons, and up to 3 TeV for protons. Throughout, we have used the simulation program CORSIKA (version 6.019 [4]), with experiment-specific extensions; the extensions define three different telescopes: the existing MAGIC telescope, a MAGIC-HQE in which all parameters remain unchanged except the camera, equipped with high quantum efficiency photosensors, and ECO-1000, which is taken to have a high-QE camera with the same angular coverage as MAGIC, and a useful mirror surface of 1000 sq.m.

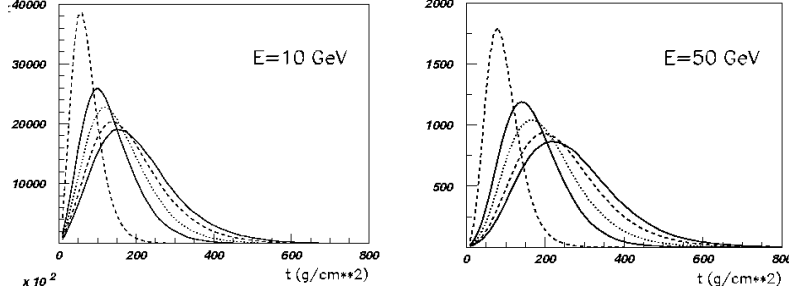


Figure 5: *Longitudinal distributions (the average number of generated Cherenkov photons) for different simulated primary energies and zenith angles in γ cascades, along the vertical direction; the broadest distributions are for zenith angle 0, the others are for 25°, 40°, 50°, and 70°.*

E(GeV)	zen = 0°	zen = 25°	zen = 40°	zen = 50°	zen = 70°
5	0.22	0.21	0.20	0.19	0.15
10	0.46	0.44	0.42	0.40	0.32
20	0.94	0.92	0.87	0.83	0.68
50	2.44	2.40	2.27	2.16	1.78
100	5.02	4.90	4.67	4.45	3.66

Table 1: *The average total number of Cherenkov photons created in γ cascades, for different zenith angles, given in millions.*

Characteristics of γ Showers at few GeV

In Cherenkov experiments, the detection quality of γ -initiated showers is directly related to the density of the Cherenkov photons reaching the telescope. Differences in their characteristics are critical in discrimination against hadrons, the dominating background. We have done extensive simulations, for different primary energies and zenith angles. The altitude (2200m a.s.l.) and the geomagnetic field of La Palma were used. We summarize in the following some characteristics of γ showers.

The average total number of Cherenkov photons created in a γ shower is given in table 1, and their longitudinal profile shown in figure 5. The average total number of Cherenkov photons in the shower is weakly dependent on zenith angle, and it increases with the primary energy.

The number of charged particles in γ cascades, shown as a function of depth, has a maximum depending on energy; it occurs at different (vertical) depths in function of zenith angle (ZA). The maximum value does only weakly depend on the ZA, but the penetration depth at higher ZA shrinks substantially. In low energy showers, below 100 GeV, no charged particles penetrate to the observation level.

All charged particles with energy above the Cherenkov threshold² contribute to the Cherenkov light pool. The average number of Cherenkov photons produced in the atmosphere is shown as a function of thickness in figure 5. The distance between shower maximum and the observer increases with the zenith angle.

The average *spectrum* of Cherenkov light at observation level is shown in figure 6a, in comparison with the originally generated spectrum. As an example, 5 GeV γ

²the threshold is given by $v \geq c/n$, with n = index of refraction

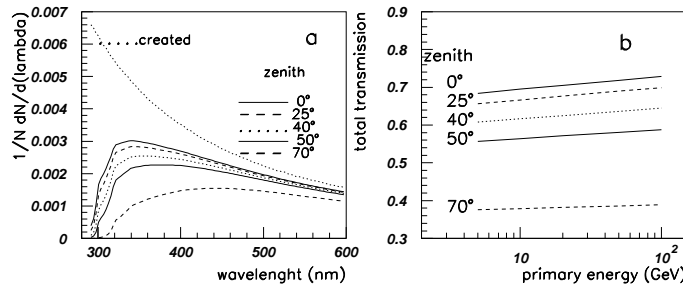


Figure 6: a) Average spectrum of Cherenkov photons after atmospheric absorption from 5 GeV γ -s, at different zenith angles; b) Average total transmission (probability to reach ground) versus the primary energy, at different zenith angles

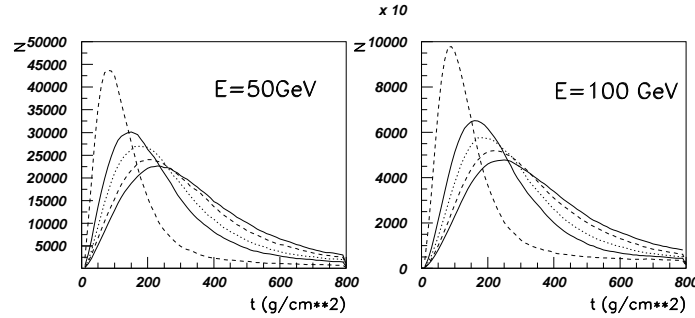


Figure 7: Longitudinal distributions (the average number of Cherenkov photons versus thickness) in proton showers, for two simulated primary energies and several zenith angles (the broadest curve is for zenith angle 0, the others are for 25°, 40°, 50°, and 70°); the thickness is measured along the vertical direction

rays were chosen. The average total transmission (viz. the fraction of light reaching ground) for all simulated energies and zenith angles was calculated and plotted in 6b). The average total transmission of the light from the shower is only weakly energy dependent, but it decreases very clearly with the zenith angle.

The average lateral density distributions were calculated in the plane perpendicular to the shower axis, for distances from the shower core up to 600 m. The curves approximately scale with energy, the well-known peak position shifts with increasing zenith angle Θ from 120 m for $\Theta = 0$ to more than 300 m at $\Theta = 70^\circ$. For fixed energy, we see the plateau of photon density decreasing with Θ . Figure 8 shows the typical lateral distribution.

Characteristics of low-energy Proton Showers

Cosmic rays, mostly protons and Helium ions, are the dominating background in γ observation. Their total rate is known from measurements, e.g. [5]. We have extensively simulated and analyzed proton showers. The longitudinal development of proton showers shows that, on average, several charged particles reach the observation level (La Palma altitude), unless the energy is low (for protons, this means $<100\text{ GeV}$)

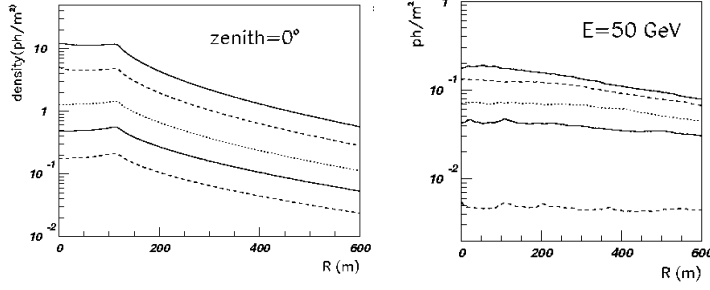


Figure 8: Average lateral photon density; left: for gammas, at different energies (highest: $E = 100$ GeV, lowest $E = 5$ GeV); right: for protons at 50 GeV, for different zenith angles (highest for $\Theta = 0$, lowest for $\Theta = 70^\circ$). The behaviour for different E and Θ is similar for gammas and protons.

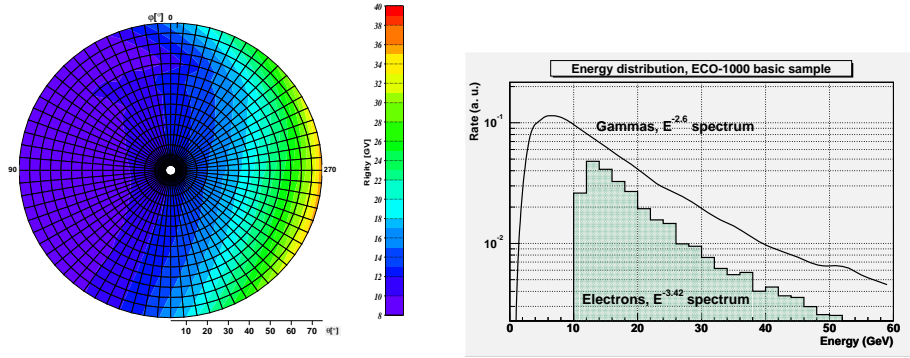


Figure 9: Left: the direction-dependent cutoff rigidity for electrons above La Palma. Right: the sharp cut caused by inclusion of the geomagnetic field (Monte Carlo events); the upper curve gives the gamma spectrum triggered in ECO-1000, the lower curve corresponds to electrons with geomagnetic cutoff (arbitrary units).

and the zenith angle large. This fact is reflected in figure 7, which shows the number of created photons as a function of the penetration depth. This being different from gamma showers, the effect contributes in discriminating gammas and hadrons, as does the narrower concentration of gamma showers.

The lateral density distribution of Cherenkov photons does not show a clear limitation of the light pool, with a peak, as do gamma showers; it simply falls with the distance from the core axis, as shown in figure 8.

Diffuse Electron Background and the Geomagnetic Field

At low energies, below 100 GeV, say, the background introduced by diffuse electrons [6] adds to the hadron background (at higher energies, the rate falls rapidly); being difficult to reduce, as electromagnetic showers have the same shape for electrons and gammas, we have looked into this background in some detail. At such energies, one has to take into account the geomagnetic cutoff [7]: the earth magnetic field deflects low-energy particles before they can reach the atmosphere. The geomagnetic cutoff is dominated by the magnetic field within few earth-radii; it does not depend on solar activity and can be assumed constant over extended periods of time. This cutoff can be calculated analytically for a dipole field [8]; for our needs, we used a more precise

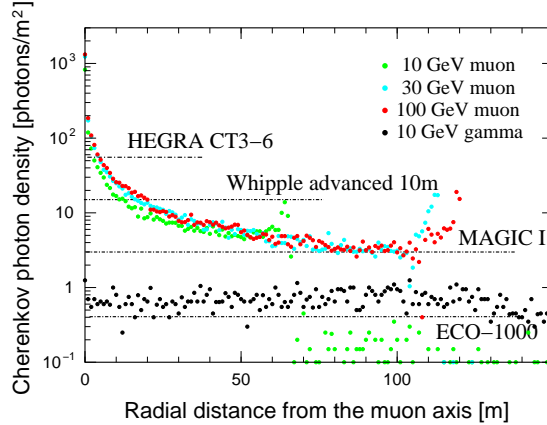


Figure 10: *The lateral distributions of the Cherenkov photon density from single muons, for different particle energies. Green, blue, and red dots denote 10 GeV, 30 GeV and 100 GeV muons, respectively; for comparison, 10 GeV gammas are also given (black dots)*

tracing program [9], containing a model of the geomagnetic field, and calculating for any position and incoming direction the probability for a particle with given charge and rigidity³ to reach the atmosphere. Compared to the energy resolution of IACTs, this cutoff is very sharp (see figure 9).

We have estimated the electron rates in the telescope, based on showers simulated in the energy range 2 to 200 GeV for various zenith and azimuth angles, and using the energy distribution of electrons from [6]. The geomagnetic cutoff and standard analysis significantly reduce the expected electron background, the residual rates after trigger and after analysis are much below proton rates, see table 2 below.

The action of the geomagnetic field on *showers* also is one of the factors limiting the performance of IACTs at low energies: the Lorentz force acts on the charged particles in electromagnetic showers. They get deflected, mostly in an East-West direction, and some get trapped in the atmosphere. We have estimated this influence using Monte Carlo data for showers arriving under different azimuthal directions, basing ourselves on geomagnetic field maps as available for La Palma. We also have looked at the effect of the geomagnetic field on the effective collection area. The conclusion is that the effect is quite visible, and will require correcting flux measurements, at γ energies below 100 GeV and for zenith angles 30° and larger. Possibilities to correct also the image parameters for individual events are under study; it is likely, however, that the classical way of analyzing events via few image parameters will have to be substantially revised at low energies, independent of the field (see also section 6).

Isolated Muon Background

Muons originating inside hadron showers can constitute a source of background. Muons travel a long path and often are above the threshold of Cherenkov radiation, a potential problem in case of high-energy showers. At lower energies, muons are not a dominating background: for once, lower energy primary particles generate only a small number of muons, and secondly, muons generated from lower energy primary particles such as ≤ 50 GeV, are less energetic themselves, and are mostly below threshold.

Figure 10 shows the lateral Cherenkov photon density at 2200m a.s.l. as function

³rigidity is defined by particle momentum / charge

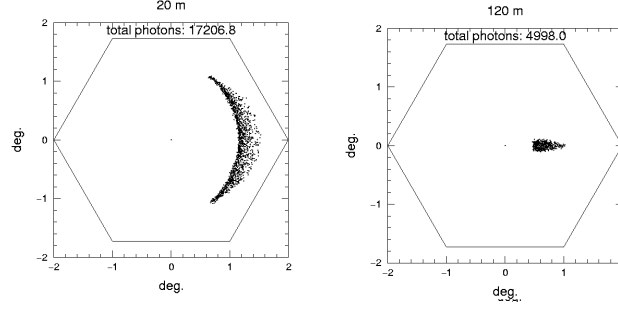


Figure 11: *Simulated single muon images in the camera plane. The images of muons impinging parallel to the telescope axis are shown for impact parameters 20 m and 120 m. The average total photon count is also indicated*

of the impact parameter and for different muon energies. There is a rather sharp cutoff in the impact parameter distribution for low energy muons: the angle between the Cherenkov photons and the muon trajectory is almost constant and small, $\sim 1^\circ$. The ECO-1000 telescope (like MAGIC) can see the single muon up to the end of this cutoff. At higher energies, the Cherenkov angle is larger and the collection area for muons increases.

A muon image in a Cherenkov telescope depends only weakly on the energy. For lower energy particles such as ~ 10 GeV, a muon image is typically brighter than a gamma image, if the particle is close to the telescope; however, muon and gamma images look quite different, they are easily distinguishable in most cases. Single muon images on the camera plane corresponding to different impact parameters are shown in figure 11, for muons parallel to the telescope axis. A full or partial ring can be seen up to an impact parameter ~ 40 m. Typically, MAGIC or ECO-1000 will either not trigger on such tracks, or they are easily discarded by image analysis. For the images with impact parameters ≥ 40 m, images become increasingly more similar to those of gammas. The muon images are elongated towards the camera center (for muons parallel to the telescope axis). Muons travel over a large distance at high altitude, and the change of Cherenkov angle is substantial; the length of the image (i.e. the width of the muon ring) reflects this variation of Cherenkov angle. Some images of muon events do indeed resemble gammas, for large impact parameters, as shown in figure 11. Such events might be able to pass gamma selection criteria and add to the background, somewhat deteriorating the sensitivity of the telescope.

In the analysis, we have additional handles to eliminate muons: we can use, for instance, the ratio of the image parameters *size* and *length*; as Cherenkov light is emitted isotropically in azimuth, and the radiated light per length is almost constant, this parameter indicates that muons, on average, radiate over a longer distance, and it allows good discrimination, as seen in figure 12. A cut which retains 80 % of the gammas, removes 95 % of muons for ECO-1000, and 82 % for MAGIC. Further, the total photon count of muon events is higher than that of low-energy gammas (≤ 30 GeV), an additional parameter allowing better γ/μ separation.

Background Light

The background light of the night sky (LONS) is another factor in analyzing image data from air Cherenkov telescopes. In measurements of the Cherenkov photons from air showers, one invariably also integrates LONS, because of the overlapping spectral distributions of these two different light sources. Although Cherenkov flashes are ex-

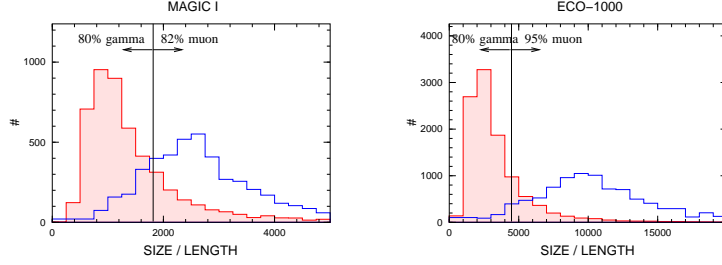


Figure 12: *Distributions of the ratio size/length for MAGIC and ECO-1000. Red (hatched histogram, left) and blue (right) distributions denote gamma and muons respectively*

	all protons triggered	all protons analyzed	μ -events triggered	μ -events analyzed	electrons triggered	electrons analyzed
MAGIC	302	7.2	155	2.6	3.95	0.52
MAGIC-HQE	313	13.1	155	3.9	5.25	0.69
ECO-1000	820	144	290	16.6	36.9	12.9

Table 2: *The expected rate per second for contaminating proton showers, for proton showers with muon content, and for electrons. More explanations are given in the text.*

tremely short, and signal integration extends over few nanoseconds, the high intensity of LONS and the relatively large size of the imaging camera pixels (with a typical aperture of $0.10\text{-}0.25^\circ$) result in some unavoidable noise component from LONS in the signal. A large telescope mirror, as foreseen for ECO-1000, will require increasing the trigger threshold by a factor ~ 2 , in stand-alone operation, to avoid a high trigger rate due to LONS alone. On the other hand, for operation of several telescopes in coincidence, the trigger threshold can be substantially reduced, although the behaviour at low energies is subject to more fluctuations, and has yet to be fully understood.

The main contributions to the LONS are the airglow (excitation of air molecules high in the atmosphere during the day time and slow de-excitation during the night), the direct starlight, the integrated starlight, the zodiacal light (scattered sunlight in the ecliptic, depending on seasonal factors and latitude) and the aurorae (latitude and solar wind dependent). For sources in our galaxy, the light emission from the Milky Way makes the LONS several times higher than the LONS at high galactic latitudes.

Background Rates

The above discussion has concentrated on background properties; it remains to show the expected rates of the various background components.

The most important background is that of hadronic showers initiated by cosmic rays. We can define *muon events* as events whose ratio of the muon-induced light in the camera to the total collected light is larger than 0.1. If we follow the overall rates as in [5], we find from our simulations the rates as in table 2. The attributes 'triggered' and 'analyzed' refer to crudely selected events and to events sent through standard analysis with gamma/hadron separation, as done for high-energy gammas. As will be argued in section 6, these are undoubtedly pessimistic rates.

One notices that the total hadron background for ECO-1000 is about three times higher than for MAGIC: this is primarily a consequence of the lower energy threshold, as can be seen from figure 13. We refer again to the discussion in section 6. For muon

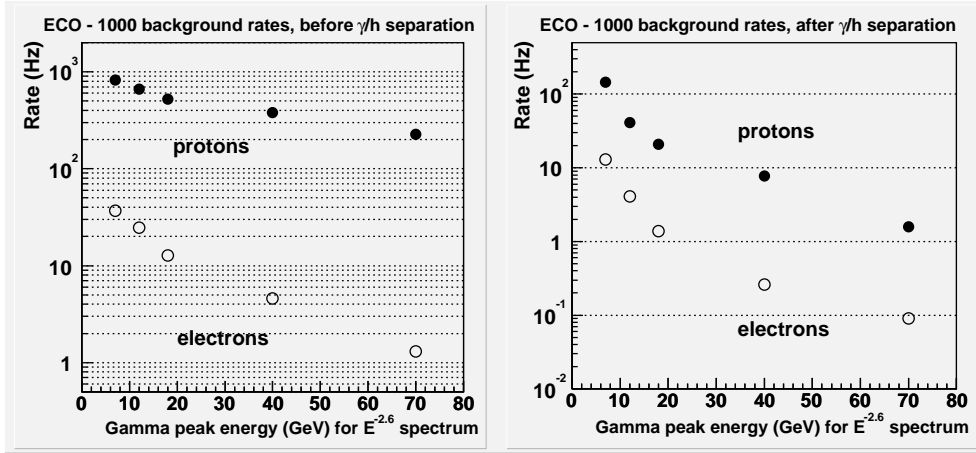


Figure 13: *The figure shows the integrated proton and electron rates, at trigger (left) and analysis level (right), in the ECO-1000 telescope. The event samples were selected by the minimal total number of analyzed photons in the image. This selection clearly purifies the gamma sample, but also shifts its energy peak, viz. the energy threshold, shown on the x-axis.*

events, the ratio is smaller, for electrons the rate is negligible. He nuclei add some 15 % to the proton rates.

For the background light (LONS), we have carried out measurements at La Palma [10], which allow to conclude⁴, for the interesting wavelength range of 300-600nm, that the normalized LONS can be described by $\sim 2 \times 10^{12}$ photons / (srad sec m²).

With this intensity and the parameters of MAGIC, we estimate that LONS induces on average ~ 0.16 photoelectrons per nanosecond and per pixel in the imaging camera. Note that the PMT pulse integration time for MAGIC at the output of the receiver board is ~ 2.5 ns (*FWHM*) and the resolution time for the trigger (gate) is 4-5 ns. The light yield for ECO-1000 will be four times higher (for the ratio of mirror areas), somewhat reduced for a shorter integration time; this assumes that pixels of the same angular coverage are used as in MAGIC.

5 Optimizing the Signal-to-Background Ratio: Conceptual Choices

Choice of site

We propose as site for the European Cherenkov Observatory the Roque de los Muchachos, La Palma, the southernmost European territory. We plan to develop the site starting with the current MAGIC telescope. An eventual configuration including two or three 17m \oslash MAGIC telescopes with ECO-1000, all equipped with high QE cameras, will be a powerful stereo system. The La Palma site (28.8° N, 17.8° W, 2200 m a.s.l.) is in many aspects very favourable, both for astrophysics questions and for infrastructure issues. A list of arguments, certainly incomplete, is the following:

- a large section of the deep sky is visible, without obscuration by the galactic

⁴the LONS intensity measured in a wide-angle pixel is clearly higher, after normalization for the field of view: this is related to an additional contribution from bright stars, more likely as the viewed part of the sky increases; our measurements showed that the normalized LONS intensity integrated in one steradian is almost twice as high compared to that measured in an angle $\leq 1^\circ$

plane with its high light background, i.e. the northern sky is better suited for example for AGN and GRB studies;

- the galactic center is still well visible with a large collection area, with the energy threshold close to 25 GeV (i.e. with ECO-1000);
- the best studied object acting as a standard candle, the Crab nebula, is well visible from La Palma. It should take less than a few minutes to carry out calibration measurements with high significance ($>8\sigma$);
- optical visibility and weather conditions on the La Palma site are among the best world-wide;
- the Canarian islands are the best suited place for an observatory on European grounds because of its most southern location in Europe;
- the small-size island La Palma has unprecedented night time temperature stability, because it takes on average half an hour to exchange the daily warmed-up atmosphere by a very stable air mass from the sea, i.e. the telescope is not affected by temperature changes during nights;
- the site has already a very good infrastructure developed both for optical astronomy and for the current gamma astronomy installation. Wide area connection to the European data nets are installed;
- the traffic connection to the main centers in Europe is excellent, i.e., the site can be reached during daytime within a few hours, and observations can be started the same evening;
- on-site prospects to carry out simultaneous gamma and optical observations (AGNs, GRBs) are excellent, apart from the fact that MAGIC has already a close partnership with one of the multiple optical telescopes on La Palma, the KVA telescope;
- the population and local authorities have demonstrated a very positive attitude towards the needs of astronomical observations. There exists a special law to suppress background light from towns at the sea level.
- an observation site in the Northern Hemisphere is a necessary complement to the likely southern gamma-ray observatory, also in build-up.

We want to elaborate briefly on the argument of altitude, i.e. compare a high altitude installation (5000 m) [11, 12] with one at medium altitude (2200 m). At high altitude, the telescope is closer to the shower maximum; the Cherenkov light pool is smaller in area, and the intensity of photons/m² is higher, i.e., the threshold for an equal size telescope should be lower. Being closer to the shower does pose optical imaging problems, though, due to the limited depth of field of a single mirror imager. Therefore, the diameter of the mirror has to be kept significantly smaller than for an installation at 2200 m, where the collection area is larger by nearly a factor of two. A camera with high QE, red-extended hybrid PMTs will be a bonus, making up for the higher losses in case of observations at large zenith angles. Our long experience of working with different types of photosensors, always in collaboration with industry, should give our

collaboration an excellent basis to install a novel type of camera on a short time scale. The cost of building a high-QE camera will be more than balanced by the additional cost for a high altitude installation. In addition, with our acquired capital of know-how (having built the world-wide largest IACT) and our possibilities to test the new technological improvement at the La Palma site, we will further cut costs and also accelerate developments in general. It should also be mentioned that the La Palma site has enough room to install a stereo system of several ECO-1000 telescopes; in addition, a site of $>1\text{km}^2$ with slightly worse background light conditions is available on the neighbouring island Tenerife.

Multi-telescope configurations

We have at present initiated the construction of a second telescope of the MAGIC class, largely unchanged from what is already installed in La Palma. This will give us, on a short time frame, several important advantages:

- substantial flexibility in using the two telescopes either in coincidence mode on the same source, or observing two different sources, e.g. during GRB alarms;
- twofold mirror area, improving our capabilities in observing a single source;
- additional information for events falling into the overlap area, resulting in improved parameters and background rejection, and thus higher-quality events useful for normalizing the observations taken outside the overlap area;
- an improved duty cycle, maintaining physics capability also during maintenance periods or technical runs;

At the time of introducing a second MAGIC, we will be able to count on a substantial experience with the first telescope, such that its running-in period will be much shortened (as will, of course, be its construction time).

We hope that we can improve the overall performance of the European Cherenkov Observatory by including advanced technical developments in the second MAGIC-type telescope, as this note suggests. Eventually, the experience in building it will enable us to propose a telescope of the ECO-1000 class, within the next two or three years.

5.1 Expected Performances

Energy Threshold, Collection Area, and Sensitivity

Energy distributions after a conservative trigger ensuring acceptable data rates, are shown in figure 14, for ECO-1000, MAGIC-HQE, and MAGIC. The energy threshold is defined to be at the maximum of the differential energy distribution. Changing the trigger conditions can lower this maximum, but rates increase and the data quality suffers. The peaks shift somewhat after analysis, and are found at 7, 25, and 35 GeV for the three telescopes, respectively, for zenith angles up to $\approx 30^\circ$. Beyond, the threshold increases with the zenith angle; at 50° , it is about 19, 80 and 125 GeV for the three telescopes, respectively.

Collection areas are shown in figure 15; again, they reflect the different energy thresholds. Sensitivity estimates at energies below 100 GeV from a specific low-energy Monte Carlo simulation are shown in figure 16. We see that at all energies the telescope sensitivity improves by introducing more efficient photosensors, and again by increasing the mirror surface, and the gains in energy threshold from MAGIC to MAGIC-HQE

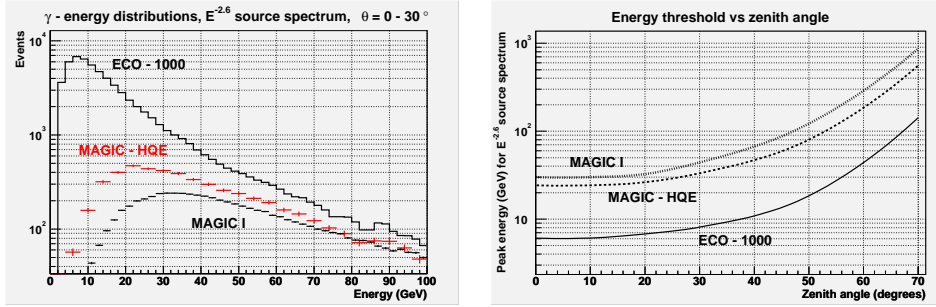


Figure 14: *Left: energy distributions at zenith angles up to 30° , for ECO-1000 (highest curve), for MAGIC-HQE (middle) and for MAGIC I (lowest); right diagram: the energy threshold dependence on the zenith angle (for a different, loose trigger condition)*

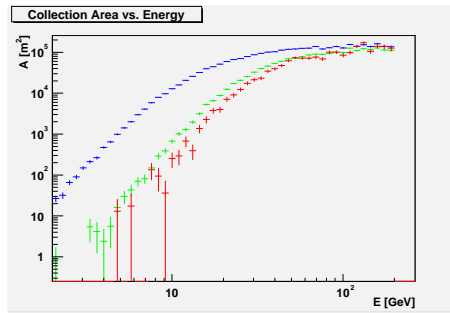


Figure 15: *Collection areas for ECO-1000 (blue, leftmost) MAGIC-HQE (green, middle), and for MAGIC (red, rightmost)*

to ECO-1000 are substantial. Two telescopes run in coincidence (in this case at 85m distance) do not reach the low energy threshold; this is much in agreement with the discussion in section 6, and clearly needs further study. The proton background flux was assumed to follow [5], He ions were not considered.

6 Analysis of low-energy Gamma rays

6.1 Gamma-Hadron Separation

The separation of the signal events, caused by gamma ray showers in the atmosphere, from the background of cosmic rays, is a critical performance parameter for Cherenkov telescopes. The background, typically hadronic showers initiated by protons or He ions, usually dominates the signal by at least two to three orders of magnitude, depending on the source being observed. Much of this background is eliminated by the fast trigger, implemented as hardware or firmware. In case of multiple telescopes, and if only the overlapping area is being used, already the coincidence trigger can ensure a reasonably clean selection, at least at higher energies. For stand-alone telescopes, the selection must be based on the properties of a single recorded image, and is more of a challenge to the statistical analysis methods, although the final results are comparable [13, 14].

In accelerator experiments, the separation of particles and energy estimation rely on calorimetric measurements at higher energies, and use single-track information at lower energies, where the statistical fluctuations make calorimeter information less reliable.

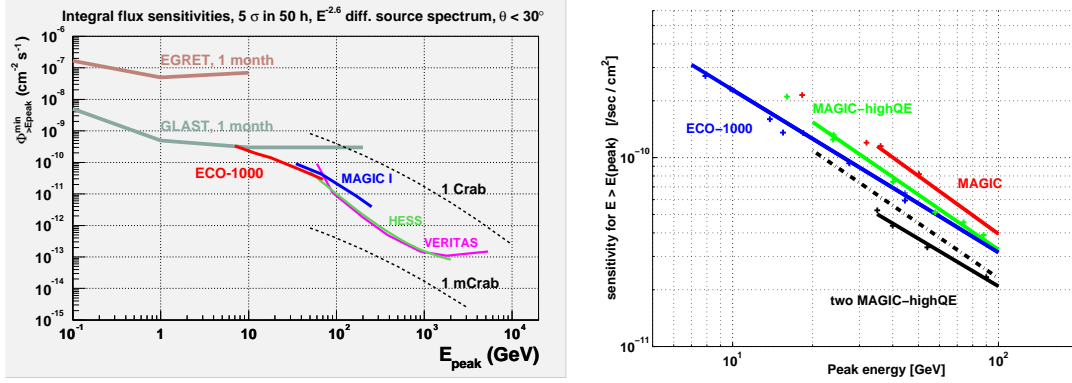


Figure 16: *Left: comparative estimate for the sensitivities of MAGIC and ECO-1000 with other instruments, existing or planned; the minimal flux for a 5σ observation in 50 hours (one month for EGRET and GLAST) of observation in stand-alone mode is given. Only the low-energy region is shown for ECO-1000 and MAGIC. Note that the curves for HESS and VERITAS correspond to multitelescope systems, 4 telescopes for HESS, 7 for VERITAS. Right: internal comparison at low energy for MAGIC, MAGIC-HQE, and ECO-1000, plus two-telescope combinations; upper points (red): present MAGIC; middle points (green): MAGIC-HQE; lower points (blue): ECO-1000, also with a high-QE camera; lowest (black) line: two MAGIC-HQE telescopes run in coincidence; the dash-dotted line gives the value for two MAGIC-HQE telescopes run in stand-alone mode. Conservative threshold energies are given by the start of the lines, points at energies below threshold correspond to events difficult to reconstruct; the power law line is only to guide the eye.*

The ground-based Cherenkov technique does not have this alternative, so we have to make the best of the information left over by the showering process in the atmosphere.

The Cherenkov light generated by electromagnetic showers at low energies, clearly below 100 GeV, can no longer be adequately approximated as a light pool of uniform illumination arriving at the detector. This is basically the assumption made by the classical analysis methods introduced by Whipple [13]. These methods rely on few parameters, to which the image information is reduced. Typically, the image of a shower, after some pre-processing, is an elongated cluster with its long axis oriented towards the camera center (assuming a point source and a shower axis parallel to the telescope axis). A principal component analysis is then performed in the camera plane (also called second-moment analysis), to obtain characteristic image parameters. Subsequently, the methods use, explicitly or implicitly, the multi-dimensional space spanned by these parameters, relying on Monte Carlo data of gamma events to define gamma properties and to discriminate them from cosmic ray (hadronic) showers. Although the basic image parameters introduced by Hillas and used in the image analysis at high energies, have been amended many times, results are deteriorating dramatically as shower energies decrease [15].

This should not be surprising: at low energy, the photons observed in the camera undergo large fluctuations in number, and in incident angle and position: the information is thinned out substantially compared to higher energy events, which fill the light cone rather uniformly. At the same time, the overall probability of detection is reduced, and an increasing number of background hadronic showers have a tendency to look like gammas, due to single π^0 -s. This is shown in the diagrams of figure 17. We plot there the *hadronness* for two different cuts in the total number of photons remaining in the analysis. Hadronness is a variable containing, in our analysis, all information used in

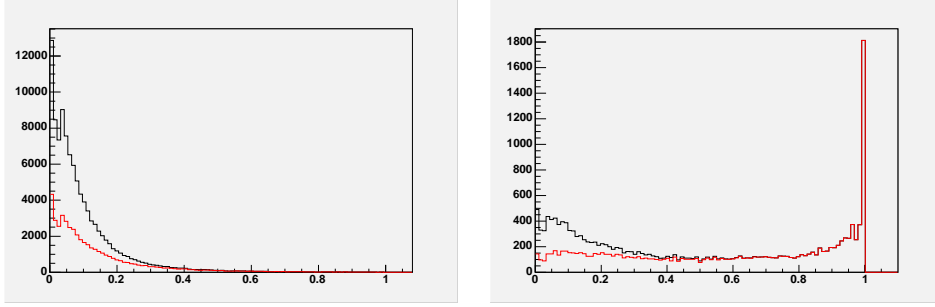


Figure 17: The probability of events to be a hadron (hadronness explained in the text, and shown on the x -axis) is histogrammed for two different cuts in the total number of photons analyzed. Left: gamma events of energy <100 GeV; Right: hadronic background events remaining after trigger.

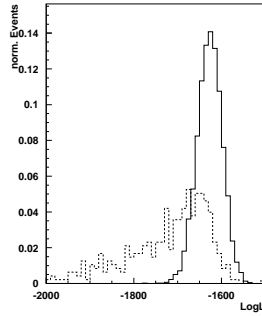


Figure 18: Log-likelihood values for MC-generated gamma (solid line) and hadron (dashed line) showers, for the MAGIC telescope

gamma/hadron separation (we use a multi-dimensional classification procedure called *Random Forest*, see [15]). Cuts in the total number of photons are related to energy cuts; they do remove the gamma-like hadron background, but also scale down severely the observed gammas - and obviously influence the energy threshold.

Our studies with low-energy events make us believe that the original method with few image parameters, developed for events with hundreds of GeV of energy, will seriously break down at energies below 50 GeV, requiring novel analysis methods. On a sample of pure Monte Carlo events in MAGIC, we have noted, using the classical separation method, reduction factors for hadronic showers (after triggering and pre-selecting events) going from ~ 400 for events above 120 GeV to ~ 10 for events below 60 GeV [15]. Some of this effect is compensated by the smaller number of triggered hadronic background events; we are also confident that the limits of analysis can be pushed further than presently known. The low-energy data now coming from MAGIC, will be of invaluable help in adjusting our analysis to this new energy range in the future.

We are working along several avenues, the most obvious being to include in the analysis some information so far untapped, like arrival time. In an alternative to the pure second-moment analysis, we include multiple new parameters, e.g. a measure of the 'lumpiness' of events: in general, the light from a gamma-ray shower is closely grouped together in the camera, while the light from a hadron shower is spread more

widely, in separate clusters. We attempt to use this by describing the shower image in the camera by a 2-dimensional function (multivariate Gauss or similar); the free parameters of this function are derived from a maximum likelihood fit, using all pixels without preceding image cleaning. A given 2-dimensional function of this type will better fit the gamma showers, and the derived log-likelihood value can thus be used to distinguish between gammas and hadrons. Figure 18 shows the distribution of this variable. The gamma sample used here consists only of showers with energies below 40 GeV.

We are also interested in using established semi-analytical methods, which fit directly physical shower parameters like energy, shower maximum, impact parameter etc. [16, 17]. They seem to perform well at higher energies, but still have to show how they deal with lower-energy showers.

So far, these studies are in an experimental stage: all analysis results shown in this note have been obtained using the classical image parameter method. At low energies, these results can clearly be considered to be pessimistic.

6.2 Energy Resolution

For higher energies, we have estimated the energy resolution using different methods, all based on various expressions involving calculated image parameters. All methods show a relative energy resolution of between 25 and 30 % for events between 100 and 200 GeV. At lower energies, the same methods can not be used without changes. The problems are due both to limits in the physics⁵ and to biases in the reconstructed event samples. Even the meaning of 'resolution' needs defining at low energy, as the statistical distributions are wide and skew, viz. highly non-Gaussian.

This work is still in progress, and subject to the remarks given in section 6. An estimation of energy without reconstruction, based on the photons that hit the telescope, results in an energy resolution of $\pm 50\text{-}60\%$ (defined as half of the width containing 68% of the events), for an incident energy of 10 GeV. More precise results at low energy will be available as MAGIC data are fully understood.

7 The Practical Implementation

The goal of our study is to prepare and test the technology for an ultra-large IACT, dubbed ECO-1000. It can be operated either as stand-alone telescope or in coincidence mode, as part of the European Cherenkov Observatory. The technology tests and studies we propose will pave the way for a rapid realization of such a telescope and will allow to make it available to the community on a predictable time scale. Current analyses have shown that within the next decade no viable alternative to the proven concept of IACTs will be available, in performance, technology and costs, for ground-based gamma astronomy.

The general technical concept is basically an extrapolation from existing, smaller-diameter IACTs; several new solutions have to be found, however, to cope with the much more demanding operating conditions of a large telescope and to achieve a lower energy threshold. Our experience in the past has been that the change from a 10 m class IACT to the 17 m MAGIC telescope did require several design changes, the

⁵low-energy showers fluctuate dramatically both in space and in the fraction observable through Cherenkov radiation

most obvious one being the introduction of the active mirror control, to overcome the support frame distortions. The envisaged linear factor two in size when going from MAGIC to ECO-1000, can be expected to again set new demands. The present note, suggesting design and feasibility studies, along with some prototyping, addresses the areas in which such preparatory work seems most relevant.

7.1 Main technical goals for ECO-1000

They can be summarized as follows:

- construction of a mirror with 34m diameter
- increase of the System Quantum Efficiency over present numbers by a factor ≥ 2.5
- improved mirrors with permanent active mirror control
- data handling capability up to 15 kHz trigger rate, and pulse height digitization with a sampling rate of 2.5 GHz (assuming the photosensor are sufficiently fast), with a 10 to 12 bit dynamic range
- repositioning time to any point on the visible sky within ≤ 15 seconds, for Gamma Ray Burst studies

Additional goals we want to pursue are the following:

- operation up to 100° zenith angle
- field of view sufficient to cover shower images from extended sources of 0.5° to 1.0° diameter, viz. $\geq 4 - 5^\circ$ in diameter
- operation also during periods of moonshine, to improve the duty cycle
- tracking precision of 0.005°
- power consumption of $< 40kW$
- price tag of ≤ 20 MEuro
- construction time ≤ 3 years

It is most important to concentrate on studies and prototype implementation of several key elements:

- Extensive, long-term and large-scale tests of a new type of high-QE hybrid photosensor, and construction of a prototype camera
- Engineering design study of the mechanics for a $34m\varnothing$ lightweight telescope construction
- Development of new lightweight, large all-aluminium mirrors of hexagonal shape and $1.3m^2$ area

- Permanent active mirror control without interference with normal telescope operation
- Detailed studies for a new user-friendly observation strategy to provide access for external users, participation in multi-wavelength campaigns and rapid dissemination of the results.

7.2 Highest priority: new high-QE hybrid photosensor

Lowering the threshold considerably below that of contemporary IACTs, cannot be achieved by increasing the mirror area alone. Optical requirements limit the maximal mirror diameter to 25-35m, depending on the telescope altitude and zenith angle. Any further increase in detection efficiency has to be achieved by increasing the conversion efficiency, i.e., the system quantum efficiency (SQE), of the initial photons to measurable photoelectrons. For a camera based on PMTs, the SQE is a product of several components:

$$SQE = \int [R_m \cdot (1 - L_{foc}) \cdot (F_{pmt} + F_{lc} \cdot R_{lc}) \cdot QE \cdot C_{d1} \cdot (1 - L_{d1})] d\lambda$$

with

$R_m = R_m(\lambda)$ = mirror reflectivity at wavelength λ

L_{foc} = Focussing losses: fraction of light not reaching photosensors (typically 10%)

F_{pmt} = fraction of active area of photosensors (typically 30-60%)

F_{lc} = fraction of area of the light catchers ($F_{pmt} + F_{lc} < 1$)

R_{lc} = reflectivity of light catcher (typically 85%)

QE = quantum efficiency of photocathodes

C_{d1} = photoelectron collection efficiency onto the first dynode

L_{d1} = losses at the first dynode including backscatter and fluctuations in the number of secondary electrons (10-30%)

For a state of the art IACT, the SQE for wavelengths between 300 and 550nm is at most 10-15%. The SQE is dominated by the low QE of the PMTs, or by the product $QE \cdot C_{d1} \cdot (1 - L_{d1})$. Given the limitations of the mirror size, the main challenge then is to improve the photosensors. In close collaboration between the MPI-Munich and Hamamatsu the company is carrying out a development of new hybrid PMTs with a high QE photocathode and an avalanche diode as electron-bombarded anode with internal gain. The cathode material, GaAsP, has a QE of 45-50% between 400 and 700 nm. Below 400 nm the QE drops smoothly to 12% at 300 nm. The use of a Silicon avalanche diode, an 8 kV cathode-to-anode voltage and an avalanche gain of 30 helps to overcome most of the losses in classical PMTs due to a nearly 100% collection efficiency, low backscatter and no additional amplification losses. The extended spectral sensitivity of hybrid PMTs is an additional bonus, because the atmospheric effects distort the original $1/\lambda^2$ shape of the Cherenkov spectrum (see figure 6a).

Smaller size prototypes are now under test and have confirmed the predictions. First measurements indicate that the gain in overall efficiency compared to a classical PMT is between 2.5 and 3.5 (zenith angle dependent). Part of the gain is due to the extended spectral sensitivity. The use of such a type of photosensor should result in a major improvement of the SQE and, in turn, a lower energy threshold and higher sensitivity. As we deal with a new device, extensive large-scale and long-term tests under realistic conditions are needed. We propose to carry out such a test by replacing part of the intended classical camera for the next MAGIC-type telescope. It is justified

to base such a test on about 15% of the number of PMTs needed for ECO-1000, i.e. 450 units. The test camera would be partially equipped with classical PMTs and partially with the new hybrid PMTs, in order to have a direct comparison.

7.3 Design study of the telescope mechanics

Based on the excellent experience made with the MAGIC construction, we plan to use again a space frame based on carbon fiber-epoxy tubes. The advantages are a reasonably stiff construction, low weight and minimal thermal expansion, as well as excellent oscillation damping. The use of CF-tubes increased the price for MAGIC by about 10%. For ECO-1000 a higher strength fiber is envisaged; industry is quite interested in such a development, and judges there exists quite some market potential.

It will be necessary to generate a detailed computer model of the telescope structure and mirror support, and to simulate numerous features:

- Stability
- Deformations at different zenith angles
- Oscillatory behaviour
- Resistance against strong storms, ice loads etc.
- Thermal expansion
- Minimization of weight
- Blueprints for the construction
- Requirements for the foundation
- Possible air turbulences, which might affect nearby optical telescopes

We may resort to an industrial offer to carry out the entire study. Several design parameters depend on the telescope support details; this study, therefore, is one of the most urgent items to tackle.

7.4 Design and feasibility study of mirror elements, prototyping

Our final goal is to build ECO-1000 with hexagonal mirror elements of 1.3 m^2 using a novel light-weight construction. We want to field-test the production mechanism by producing a limited number of mirror elements with the same method, and incorporate them in a MAGIC-type telescope. They will be square 1 m^2 , and will be produced as a single honeycomb sandwich panel, to which a native spherical shape is given during the gluing process.

The gluing procedure needs, therefore, a spherical mold on which a 8cm Al honeycomb is sandwiched between two 2mm Al plates (skins), and forced with a vacuum bag to the spherical surface of the mold. The gluing itself will subsequently take place in a pressurized oven, at high temperature (150 deg), with a cycle of pressure/temperature typical for aero-space qualified gluing procedures.

The additional cost of producing a native spherical shape is more than balanced by the savings in the milling of the raw spherical shape, both in the cost of the machining and the subsequent manual labor.

Using this technology, the thickness of the front plate does not need to be very large because it has already the right spherical shape, so the mirror can be as light as 15 kg/m^2 . This parameter is very important for the total weight budget for a large telescope.

Pre-shaping and polishing smaller mirrors has already been done successfully. Preparations for producing the first mirror of 1m^2 surface are under way, along with the tooling for the serial production. This development will have to pass through several iterations of prototyping and measurement; we estimate a total prototype production of at least 100 elements.

7.5 Design and feasibility study of the permanent active mirror control, prototyping

Larger mirror diameters put exponentially growing demands on the stiffness and weight of the support frame, if required to be rigid. Alternatively, an active mirror control can be used and thus allow for the modest deformations of a much lighter structure. Such an approach follows the trend in modern optical astronomical telescopes, although the implementations and detailed requirements are quite different. As the main mirror has to be focused on an altitude of around 10-30km, where the showering occurs in the atmosphere, it is not possible to use guide stars for the control. Instead, one can check the orientation of the segmented elements of the mirror by laser beams. For MAGIC, a system based on red lasers was used, thus requiring periodic interruption of the observations for mirror readjustments. For ECO-1000 it is planned to have a permanently active system based on infrared lasers, which do not interfere with the photosensors. Some basic development is needed, but the first suitable industrial components are available. We plan to design such a system and implement it on a small scale. Installation on some of the novel mirror elements in the next MAGIC-size telescope for long-term tests is foreseen.

7.6 Studies to prepare the European Cherenkov Observatory (ECO) for access to a much widened community

During the early phase of ground-based gamma-ray astronomy the experiments were designed and carried out similarly to high energy physics experiments at accelerators, i.e., as very specialized instruments to be frequently changed and operated for a rather limited duration by a dedicated collaboration. Also, analysis and physics interpretation could only be carried out by the collaboration. Currently, trends are to convert the detectors into facilities and to make them accessible to a much wider community. Here we mention in particular our intention to open the telescope facility to guest observers (not required to have detailed knowledge of the instrument features) and to integrate most of the physics program into multiwavelength observations. This requires a considerable change in structure and coordination of operation, data standardisation and means of fast data dissemination. An important issue will also be the availability of standardized Monte Carlo simulation packages, a necessary prerequisite for the extraction of the final results. Here we propose to carry out such a study, define the necessary changes for the operation strategies and necessary hardware.

7.7 Environmental Impact Studies

The installation of a new telescope requires studies of the environmental impact, similarly to those carried out for MAGIC. The following details have to be studied:

- Geology of the ground
- Impact on the ecosphere
- Impact on the ecosystem by the additional infrastructure
- Telescope stability in case of strong storms and in case of ice deposits
- Impact on possible historical remains
- Impact from the power release
- Impact from possible generation of atmospheric turbulences that might affect the nearby optical instruments.

This study requires outside expertise and special tests, e.g. wind channel tests.

8 Conclusion

Multiple strong arguments can be made for the extraordinary physics potential that can be tapped by gamma ray telescopes with the lowest possible energy threshold. A key instrument to aim for is a telescope with a large mirror surface and a high quantum efficiency camera. We call this telescope ECO-1000, and have presented above the necessary steps to work towards such a device over the next three years. One important step is a design and feasibility study, including some prototyping; we propose here to equip part of a MAGIC-size telescope, now under construction, with novel photodetectors, with optimized mirrors, and with a permanently active mirror control system. Use in a working telescope will not only allow long-term field testing of these components, but also improve the physics performance of this telescope. We also propose detailed feasibility studies towards an ultra-light telescope structure, based on computer modeling.

The successful completion of the proposed studies will give us confidence in the new technological features, and will allow a riskless extrapolation from MAGIC towards ECO-1000, as a final target. A proposal for ECO-1000 could be completed as early as 2007, with the goal of having an operating instrument in 2009 or 2010.

We further argue strongly in favor of using the existing infrastructure at the La Palma site for a gradual development towards a multi-telescope European Cherenkov Observatory. We intend to open this observatory to guest observers, and to make the data available to the entire international community of astronomers and astrophysicists.

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